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VACUUM DEPLOYMENT TEST OF A LARGE EXPANDABLE AEROSPACE SHELTER

F. W. Nelms
ARO, Inc.

August 1966

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NOTICES

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F. W. Nelms
ARO, Inc.

FOREWORD

The work reported herein was done at the request of the Air Force Aero-Propulsion Laboratory (AFAPL), Research and Technology Division (RTD), Air Force Systems Command (AFSC), Wright-Patterson Air Force Base, Ohio, under Program Element 62405214, Project 8170.

The expandable, self-rigidizing structure tested for AFAPL was designed by GCA Viron Division, a division of GCA Corporation, Minneapolis, Minnesota. Viron furnished the fabric portion of the structure, AFAPL fabricated the bulkheads, and Viron and ARO, Inc. assembled the structure. The design and fabrication accomplished by Viron for AFAPL was under Contract AF33(615)-2115. The cognizant contract monitor was Mr. Fred Forbes, APFT, WPAFB, Ohio.

The results of the test presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center, (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The test was conducted from March 17 to 29, 1966 under ARO Project No. SM0602, and the manuscript was submitted for publication on June 2, 1966.

This technical report has been reviewed and is approved.

James N. McCready
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Colonel, USAF
Director of Test

ABSTRACT

A 10-ft-diam by 25-ft-long, expandable, self-rigidizing, cylindrical aerospace shelter was impregnated with a water setting resin and packaged for deployment in a vacuum of 10^{-4} torr in the Mark I Aerospace Environmental Chamber. Deployment of the structure occurred at an excessively high, uncontrolled rate. The test article and support equipment suffered extensive damage, which prevented continuation of the test in the vacuum. The Mark I chamber was returned to atmospheric conditions, and the structure was rigidized.

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ILLUSTRATIONS

SECTION I
INTRODUCTION

The possible use of expandable structures in the manned space program is discussed in "Aerospace Expandable Structures Conference Transactions," AFAPL-TR-65-108, May 25-27, 1965, Minneapolis, Minnesota. The basic concept of the structures is characterized by a packaged vehicle many times smaller than its deployed configuration.

This report covers the assembly, resin impregnation, and deployment of an expandable, cylinder-type aerospace shelter whose dimensions after rigidization were approximately 10 ft in diameter by 25 ft long. The cylindrical portion, constructed of woven fiber glass flutes sandwiched between layers of urethane-coated nylon, was 18 ft long. This cylindrical section was terminated by two 10-ft-diam aspheric fiber glass and epoxy bulkheads, which also served as the structure's canister before deployment. The test objective was to determine if the vehicle would deploy and rigidize in a simulated space environment and to record the deployment and rigidization with motion-picture photography.

SECTION II
APPARATUS

2.1 MARK I, AEROSPACE ENVIRONMENTAL CHAMBER

2.1.1 General Description

Mark I, in which the tests were conducted, consists of a large cylindrical vacuum tank, pumping systems, thermal environmental systems, vibration system, controls, and instrumentation suitable for conducting tests on large space vehicles. A schematic of the facility is shown in Fig. 1. The chamber and associated equipment areas are shown in Fig. 2. The chamber is contained in a room 68 by 68 by 109 ft high. Service areas within the building provide space for test article buildup and equipment maintenance.

The Mark I chamber (Fig. 2) is a cylindrical vessel 42 ft in diameter and 82 ft in height with 0.875-in.-thick walls and 1.5-in.-thick elliptical heads. The chamber shell is constructed of 304L stainless steel for low outgassing and for good corrosion resistance.

The inside working dimensions of the chamber are 35 ft in diameter and 65 ft in height. Vehicle entrance to the chamber is through a 20-ft-diam hatch located in the top of the chamber. Personnel access to the chamber is through a hatch 7 ft in diameter near the bottom of the chamber.

Three pumping systems are available for evacuating the Mark I chamber: (1) a three-stage increment of the Propulsion Wind Tunnel Facility (PWT) plenum evacuation system, (2) a conventional vacuum pumping system consisting of roughing pumps, forepumps, booster pumps, and diffusion pumps, and (3) a cryopumping system cooled by a 90-kw liquid nitrogen and a 7.5-kw gaseous helium system.

2.1.2 Pumping System Used for this Test

The pumping system used for this test consisted of two 850-cfm roughing pumps and ten mechanical forepumps to evacuate the chamber from atmosphere to 15 torr, where two 4000-cfm Roots blowers were started; at 10^{-1} torr, four booster pumps were placed in operation; and at 10^{-2} torr the roughing pumps and Roots blowers were valved out and eleven 32-in. diffusion pumps were placed in operation. Approximately 1200 ft^2 of LN_2 cryopumping surface was used. Figures 3 and 4 show the pumpdown curves obtained with this system.

2.2 TEST ARTICLE STRUCTURE

The test article is shown in the packaged and deployed condition in Figs. 5 and 6, respectively. The structure is similar to the models tested earlier in the Aerospace Research Chamber (12V).[1]

The domed bulkheads which served as the predeployment canister were constructed of fiber glass and epoxy. Each bulkhead weighed approximately 1000 lb and was 10 ft in diameter by approximately 3.5 ft deep.

The fiber glass fabric was of a sandwich-type construction with the fluted core parallel to the axis of the cylinder (Fig. 7). Elements of the fiber glass fabric sandwich consist of a 26-oz/yd^2 inner facing fabric,

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[1]Latture, N. C. "Vacuum Testing of Expandable Self-Rigidizing Structures." AEDC-TR-65-264 (AD475243), December 1965.

an 8-oz/yd^2 core fabric, and a 10-oz/yd^2 outer facing fabric. The outer covering was identical to the urethane-coated bladder fabric except that it was not pigmented. Fiber glass sections of the fabric sandwich were joined continuously at the flute lines by an integral weaving process. The bonds between the pigmented urethane-coated bladder, the 0.25-in.-thick foam rubber, the fiber glass, and the urethane-coated nylon outer covering were made with flexible adhesives (Fig. 7). An O-ring seal was used between the two halves of the canister which were restrained by a large spring-loaded ring clamp. The clamp was released by the simultaneous firing of two explosive bolts positioned 180 deg apart on the periphery of the canister's 10-ft diameter.

The fiber glass sandwich section was impregnated with a resin which was activated by water vapor. Figure 8 shows the catalyst container and the two solenoid valves used to control the catalyst flow rate to the fiber glass fabric sandwich section. Two 2500-w heaters were installed in the container to maintain the proper catalyst temperature.

2.3 TEST CONFIGURATIONS

Two test configurations were used in the test. The first, for a shakedown run, had no resin in the fiber glass. The second configuration was used in the rigidization test.

The first configuration was an assembly of the nonresin-impregnated aerospace shelter and a full-scale model of the Gemini vehicle (Fig. 9). The purpose of using this assembly was threefold.

1. The "shakedown run" would provide an operational check of the Mark I chamber and all required support equipment.
2. All test article functions except the rigidization could be checked in the actual test environment.
3. Since the deployment of the test article was expected to occur in the same manner for both runs, motion pictures of the shelter-Gemini model assembly were made during the shakedown so that the model, which contributed significantly to the chamber pumping system gas load, could be removed for the rigidization run.

Strain-gage-type load cells were installed in the four support stands to monitor the test article's overall weight. They also indicated the amount of lifting load transmitted to the upper bulkhead from the overhead crane immediately prior to deployment via the support cables and a mechanical, vacuum tight feed through. The predeployment load on the

upper bulkhead was intended to prevent the bulkhead from falling back after initial deployment onto the fabric and lower bulkhead flange and possibly damaging the fabric.

The second configuration, the resin-impregnated shelter minus the Gemini model, is shown during installation (Fig. 8). The expanded cylinder during rigidization is shown in Fig. 10.

2.4 INSTRUMENTATION

The chamber pressure was monitored with two alphatron and two ionization gages. Copper constantan thermocouples were used to monitor the LN_2 liner temperatures, the three solenoid operated valves' temperatures, and the catalyst temperature. Four strain-gage-type load cells were used to monitor the weight of the test article (Fig. 8). Transducers were used to make the required pressure measurements. All data were recorded using a strip chart recorder and a 25-channel data logger system. Two cameras were used to provide the motion-picture coverage of the deployment and rigidization. These cameras were mounted outside the chamber and viewed the test article through portholes. One of the cameras was mounted to view the side of the extended cylinder and provided 400-frame/sec coverage for the first 10 sec of its operation, then shifted automatically to 24-frame/sec coverage. The second camera was mounted on top of the chamber and operated at 24 frame/sec. A closed-circuit television camera located inside the chamber was used to monitor the deployment of the test article.

SECTION III
PROCEDURE

3.1 PREPARATION OF THE TEST ARTICLE

The assembly of the 10-ft-diam by 25-ft-long, expandable, cylinder-type aerospace shelter was accomplished by Viron and ARO employees in the sixth floor buildup area of Mark I. After assembly, the cylinder's bladder and outer covering were leak checked using ammonia gas and a phenol indicator. The shelter was then packaged for the shakedown run. After completion of the shakedown run, the expandable structure was removed from the chamber, returned to the sixth floor buildup area, and then prepared for resin impregnation. Figure 11 shows the shelter and the handling stand used for the resin impregnation. The shelter was inflated to a pressure of 6 in. of water. This pressure provided the

rigidity required to maintain the shelter's shape in the horizontal position. Three equally spaced, 2-in.-diam by 12-ft-long tubes were inserted into the fluted portion of the fabric section to disperse the resin. A polyethylene covering was used to seal the entire nylon and fiber glass fabric portion from the water vapor in the atmosphere. The space between the polyethylene covering and the fabric portion of the cylinder was purged with dry nitrogen to ensure that no moisture would be introduced to the resin during impregnation. A vacuum pump was attached to the fiber glass section to enhance the flow of resin throughout the fluted section.

After resin impregnation was completed, the cylinder was packaged. The two bulkheads which served as the canister were brought together and fastened with a spring-loaded clamp and the two explosive bolts. The packaged shelter was then installed in the test chamber.

3.2 TEST PROCEDURE

The Mark I chamber was evacuated to the low 10^{-6} torr range for the shakedown run and to the low 10^{-4} torr range for the actual test. The higher pressure for the actual test was a result of the outgassing load (primarily resin-solvent vapor) from the test article. After the chamber pressure had stabilized and a final scan had been made of all the sensors, the motion-picture cameras were started. Approximately 2 sec later the explosive bolts were fired to initiate the deployment of the test article. After firing of the explosive bolts, the procedure was to have been to deploy the cylinder slowly by filling the bladder with CO_2 to a pressure of 6 in. of water. Figure 12 is a diagram of the CO_2 piping and valving arrangement. After complete deployment the catalyst solenoid valves were to be operated as required to release the catalyst at approximately 20 lb/hr. The vapor distribution solenoid valves were to be used to release excess catalyst and solvent vapor. Pressure was to be maintained in the bladder at 6 in. of water until the rigidization process was completed.

SECTION IV
RESULTS

4.1 SHAKEDOWN RUN

During the shakedown run pumpdown, a base pressure of 4×10^{-6} torr was reached. Figure 3 indicates that a pumping time of nearly 13 hr was required to attain this pressure. Deployment of the shelter was performed using CO_2 to pressurize the bladder section to approximately

16 torr. At this pressure, the shelter was fully expanded and supported the Gemini model without assistance from the support cables.

Motion pictures were made of the shelter-Gemini model assembly's deployment and expansion. Shelter internal pressures, several test article component temperatures, and the load cells' output were monitored during the run. All indications were that the chamber, its support equipment, and the test article would perform satisfactorily at the required chamber test pressure and temperature during the rigidization run.

4.2 RIGIDIZATION TEST RUN

A base pressure of 4×10^{-4} torr was attained in approximately 8 hr for the test of the resin-impregnated cylinder. The chamber pressure was limited because of the large gas load presented by the approximately 240 lb of solvent (butyl acetate) in the 600 lb of resin-solvent mixture used to impregnate the fiber glass section of the cylinder.

The test run was not completely successful. All systems operated normally until immediately after the firing of the explosive bolts. Complete deployment of the cylinder occurred almost immediately after the bolts released the restraining ring. The cylinder expanded unevenly, bending and leaning toward the side containing the heavy, eccentrically positioned floor. Figure 13 shows the shelter floor location. The expansion rate and the asymmetrical weight distribution caused the almost fully expanded shelter to fall to the chamber floor. The bending moments on the load cells in the support stands destroyed the cells. The pressure transducers, catalyst valves, and catalyst tank were torn from the upper bulkhead when it struck the floor and side of the chamber. Figure 14 shows the shelter 1. 125 sec after deployment began. Figure 15 shows the upper bulkhead striking the floor and chamber wall 2. 33 sec after deployment began. The violent deployment with its resultant damage precluded continuation of the test with the expanded cylinder resting horizontally on the chamber floor. The chamber was returned to atmospheric pressure. The cylinder was positioned with its longitudinal axis vertical and was pressurized to 8 in. of water gage. Rigidization of the resin-impregnated fiber glass section of the shelter was then accomplished at ambient conditions. Figure 16 shows the rigidized cylinder after removal from the chamber.

The shelter was inspected immediately after removal from the chamber. Although no structural strength tests were conducted, the fabric section was examined closely and was found to be very hard and completely rigidized. Most of the damage suffered during the violent deployment and fall

was to-the interior portion of the shelter. The bladder was torn from the lower bulkhead, and the fiber glass floor supports were cracked at the support-to-bulkhead joints Figure 17 shows the interior of the lower portion of the cylinder and the bottom bulkhead.

The pressure in the resin-saturated fluted fiber glass section of the fabric cylinder was 13 in. of water prior to deployment of the shelter. Although this pressure was higher than desired, the decision was made to deploy since indications were that pressure would not be reduced significantly during an extended period of pumping.

The cause of the expansion of the cylinder to its full length in such a violent manner was traced directly to the high pressure in the volume between the bladder and outer covering, which contained the 600 lb of resin-solvent mixture. Analysis of the data and subsequent work done by the resin suppliers indicate that approximately 63 percent of the solvent (150 lb) should have been removed from the resin-impregnated fabric to prevent the violent deployment. It is quite unlikely that this amount of solvent could have been pumped by the chamber pumping system in a reasonable time since the lower portion of the cylinder contained a substantial amount of resin in the liquid phase that could very well have been trapped within the folds of the packaged fabric, thereby preventing the solvent from vaporizing.

One method of reducing the amount of solvent in the impregnated fabric would be to purge the fluted area with dry nitrogen until the required reduction in the solvent content is attained. To keep the resin solids suspended homogeneously in the impregnated fabric after drying with nitrogen, the resin suppliers recommend minute amounts of certain inert additives in the resin-solvent mixture.

SECTION V
CONCLUSIONS

Deployment of the large aerospace shelter in a simulated space environment was not successful; however, the shelter was rigidized at atmospheric conditions. The violent expansion certainly was not desirable, but it appeared that had the shelter been constrained to prevent structural damage, a successful deployment and rigidization would have been achieved. The dramatic, though undesirable, results of this test graphically pointed to the need for further study and development of rigidizing agents for expandable space shelters.

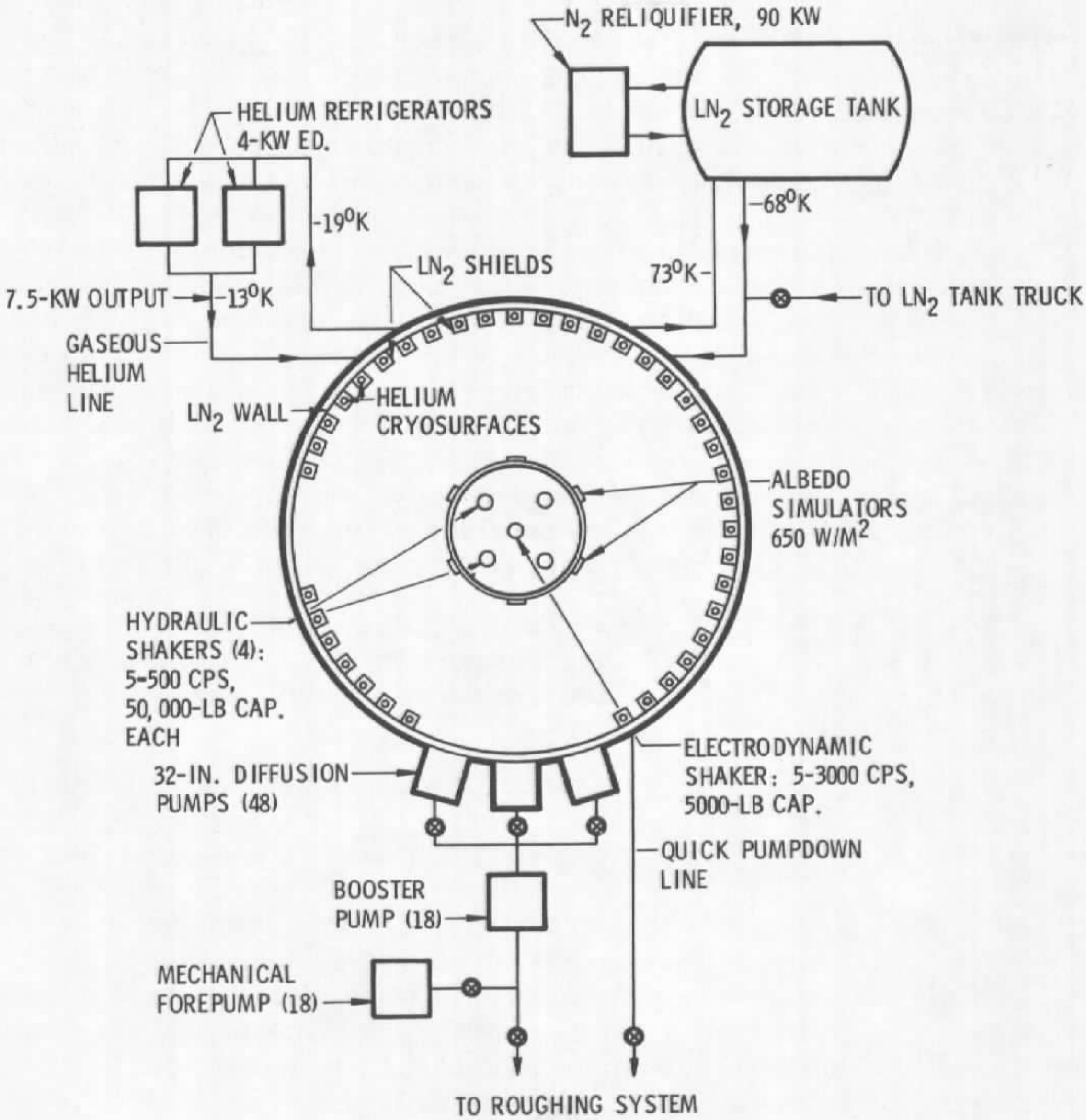

Fig. 1 Mark I Schematic

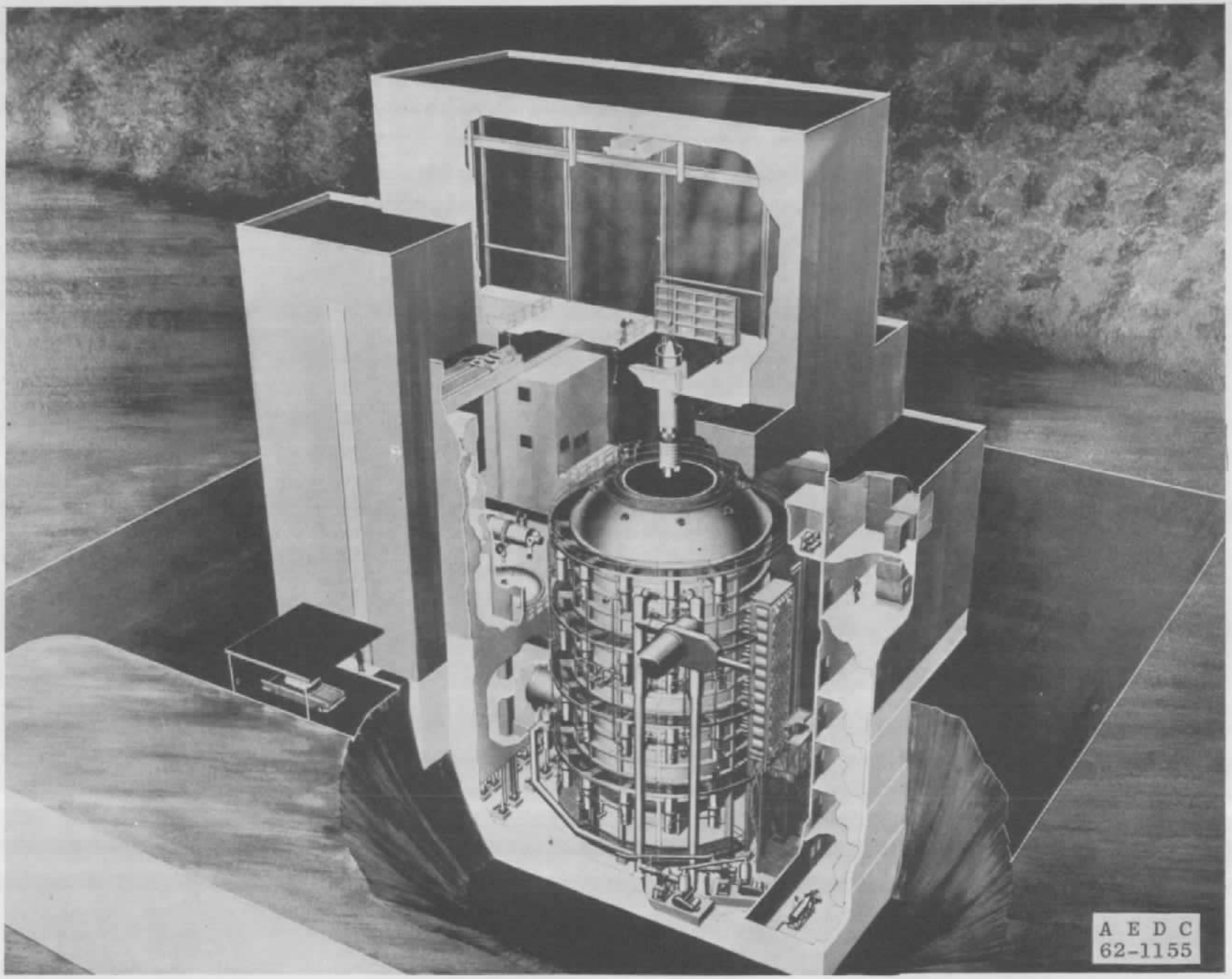

Fig. 2 Mark I Facility Arrangement

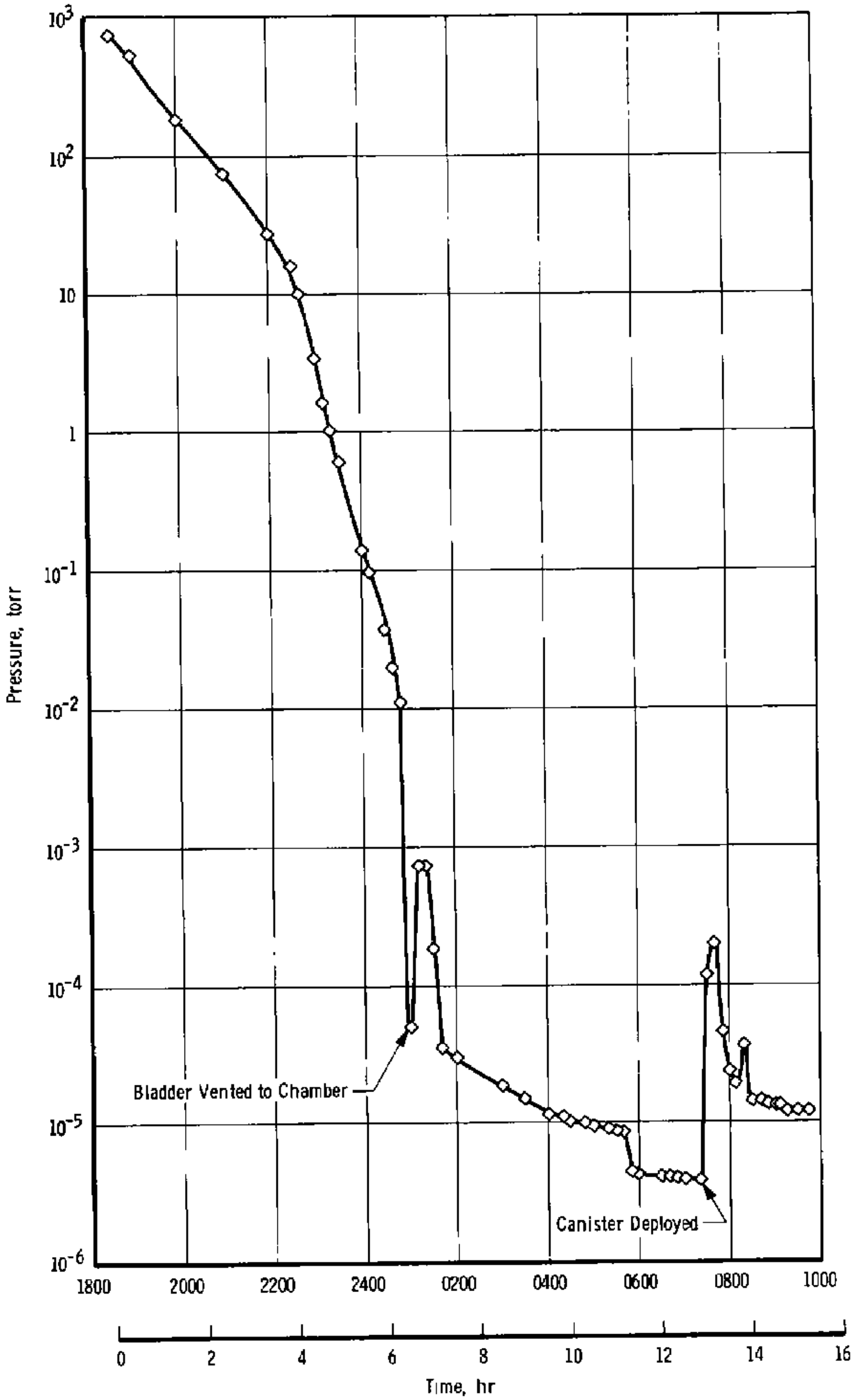

Fig. 3 Chamber Pressure, Shakedown Run

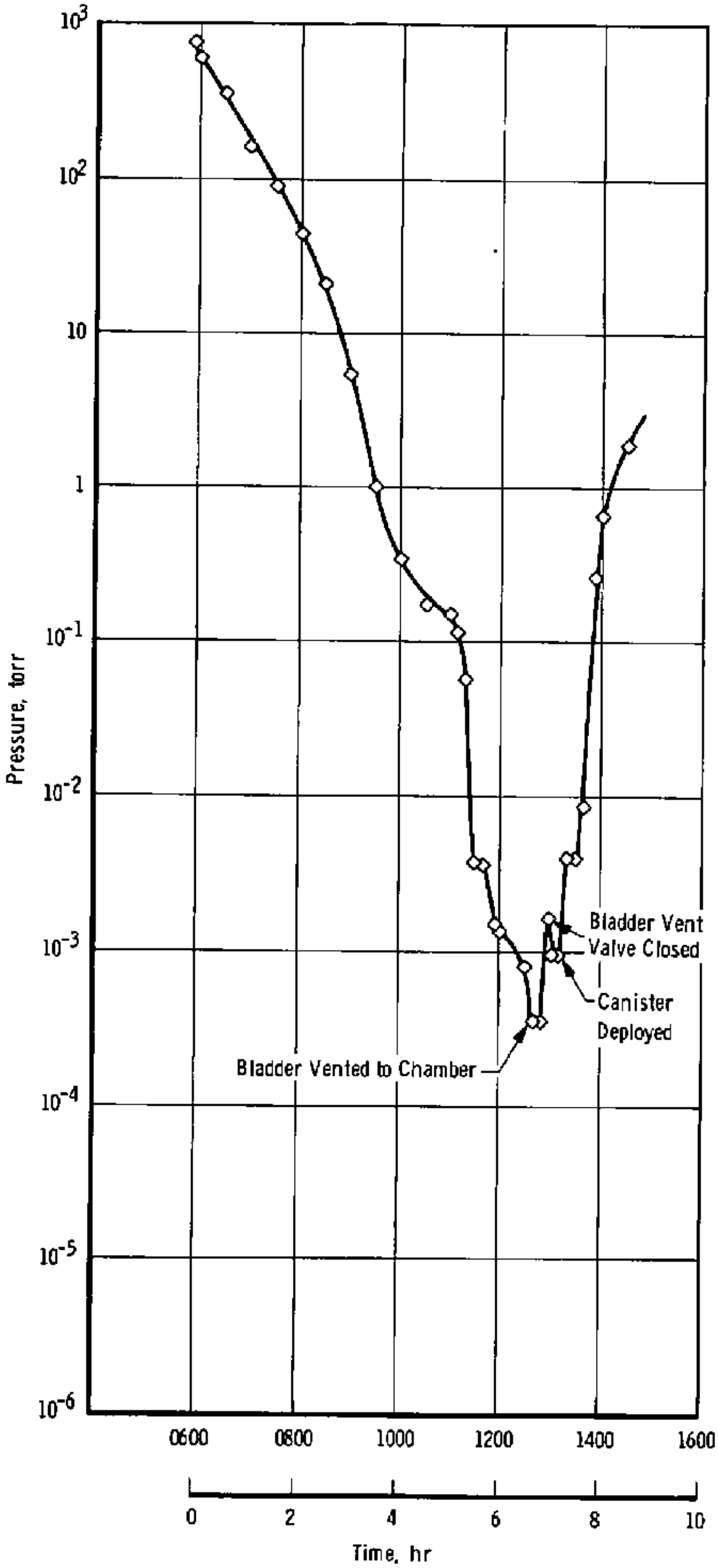

Fig. 4 Chamber Pressure, Rigidization Run

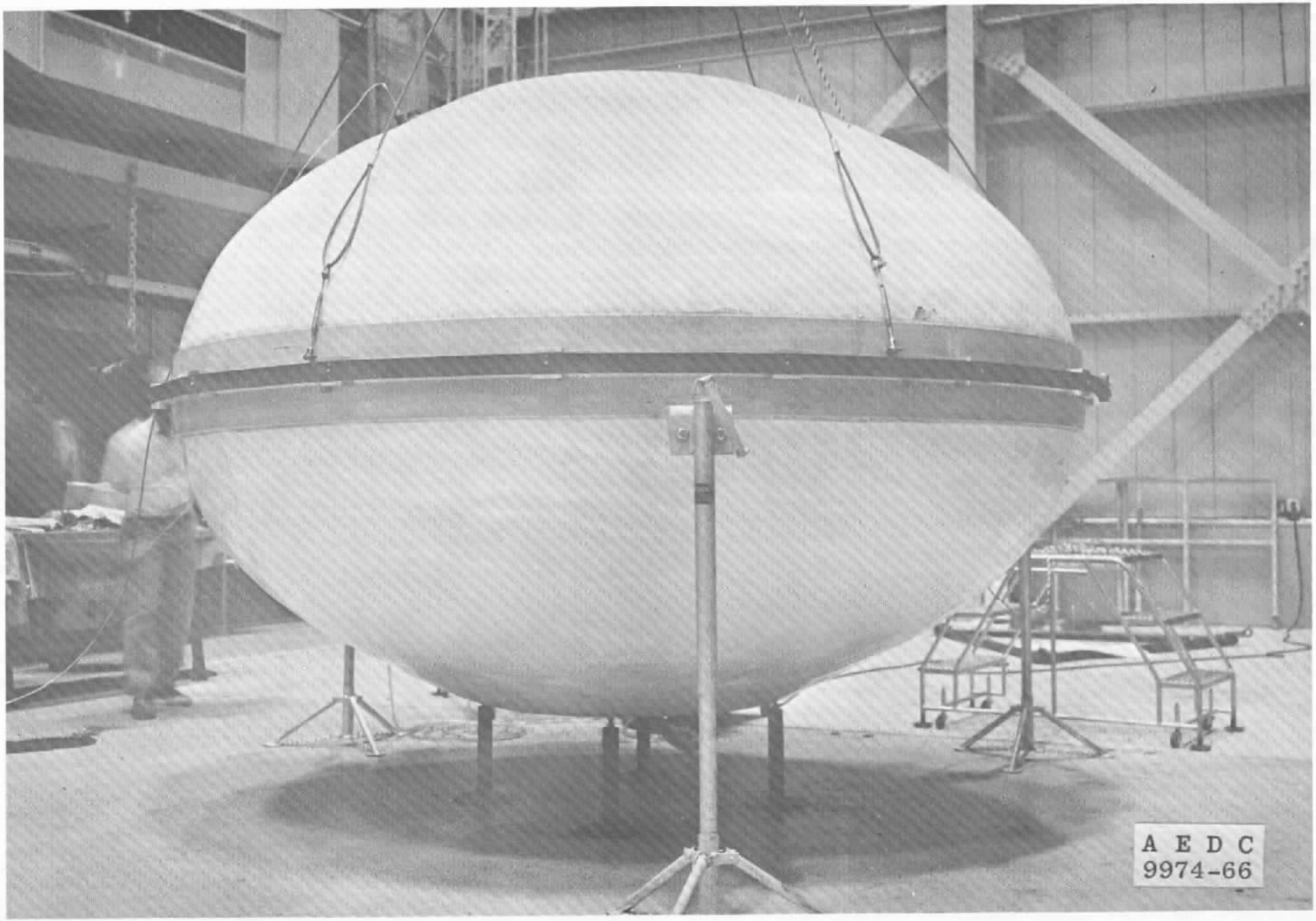

Fig. 5 Packaged Expandable Aerospace Shelter

Fig. 6 Deployed Expandable Aerospace Shelter

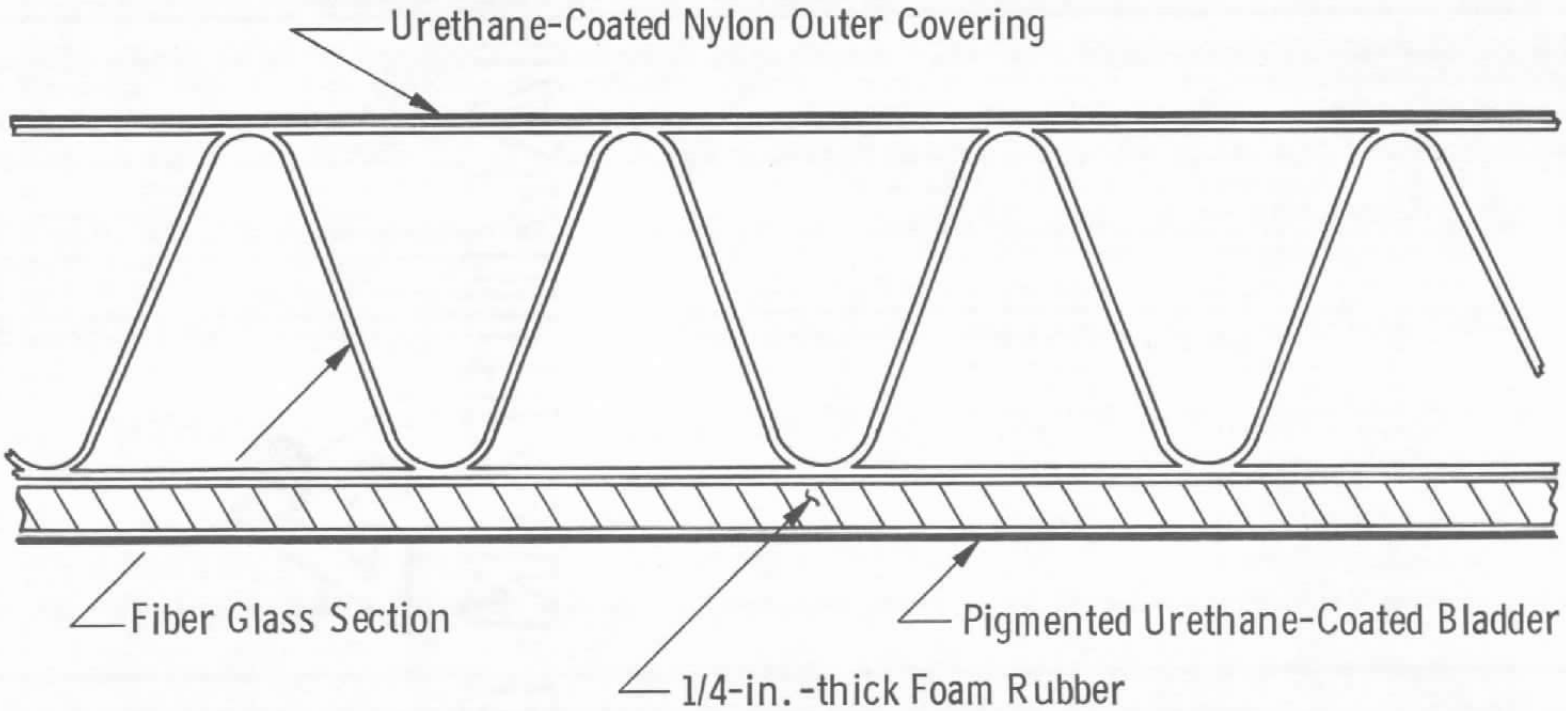

Fig. 7 Cross Section of Fabric Cylinder Wall

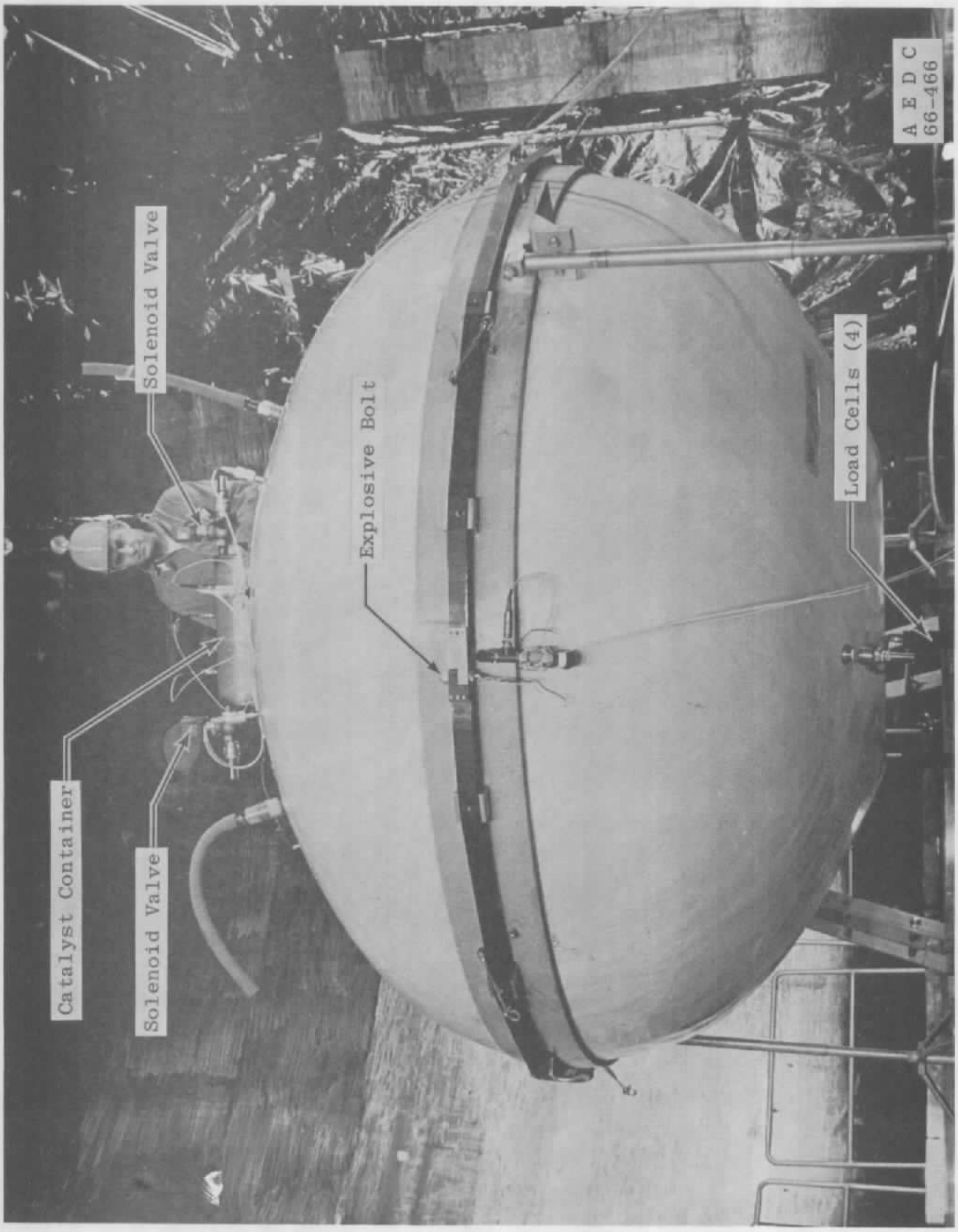

Fig. 8 Catalyst Container and Valves on Packaged Shelter

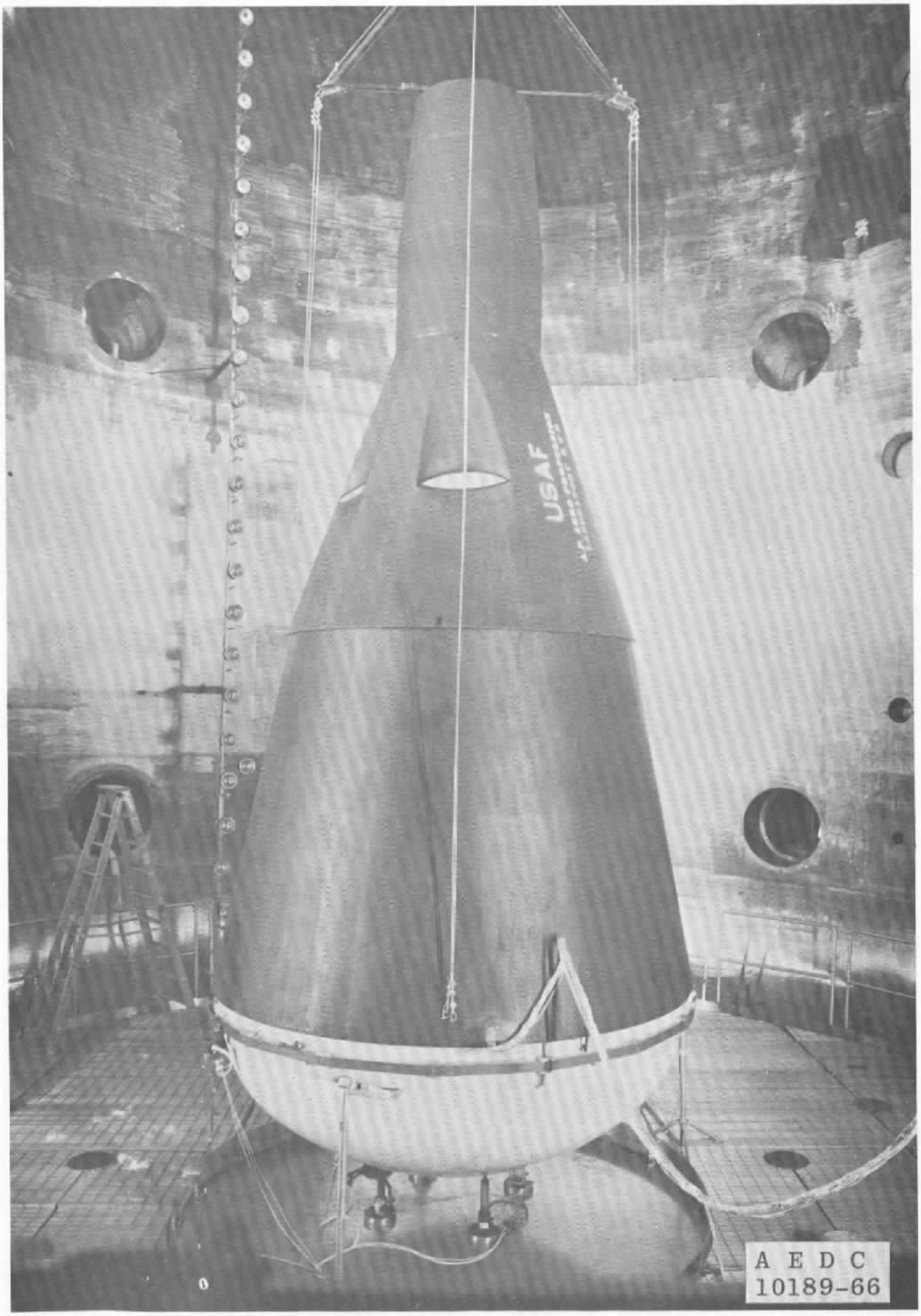

Fig. 9 Packaged Shelter and Gemini Model

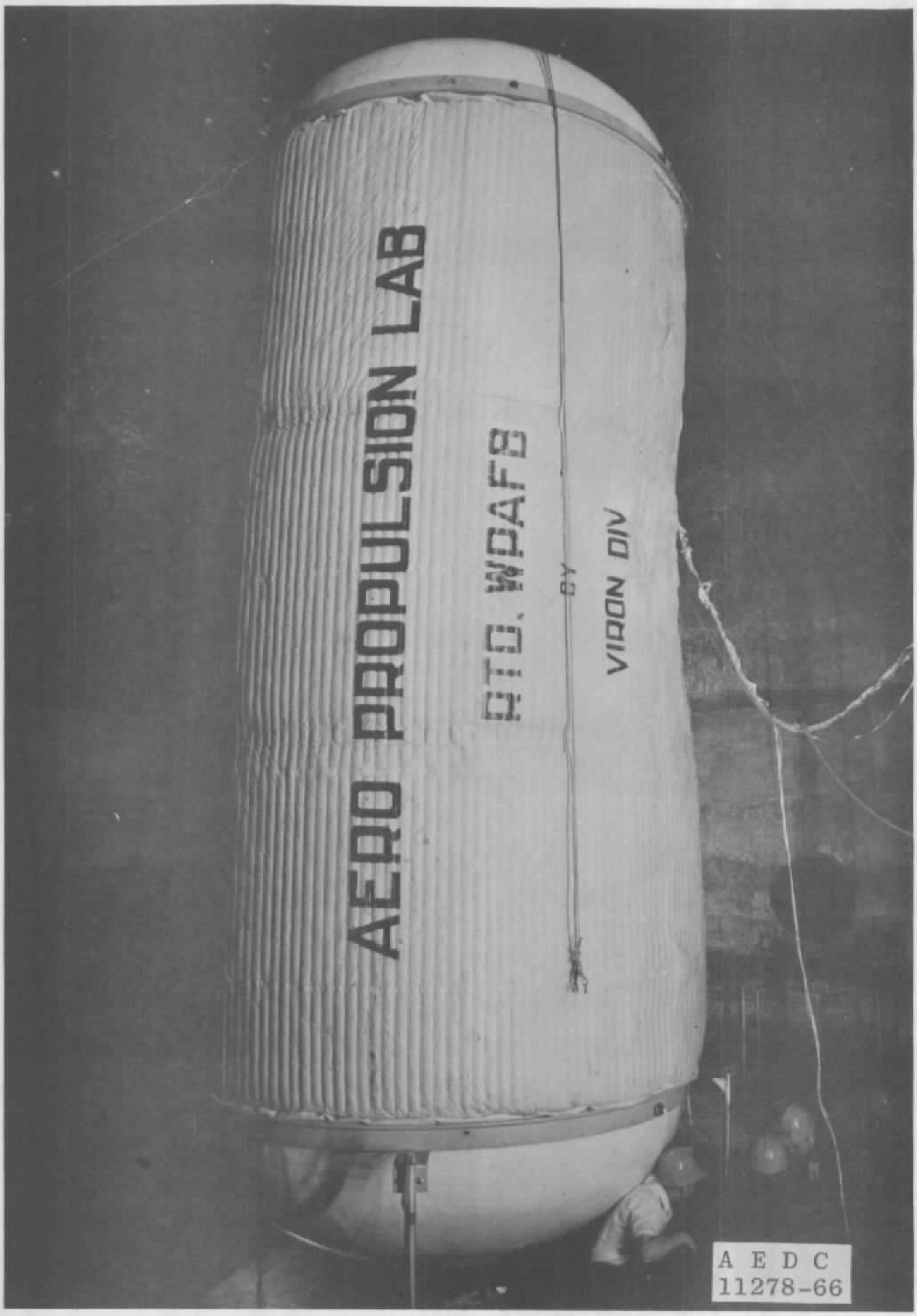

Fig. 10 Expanded Shelter during Rigidization

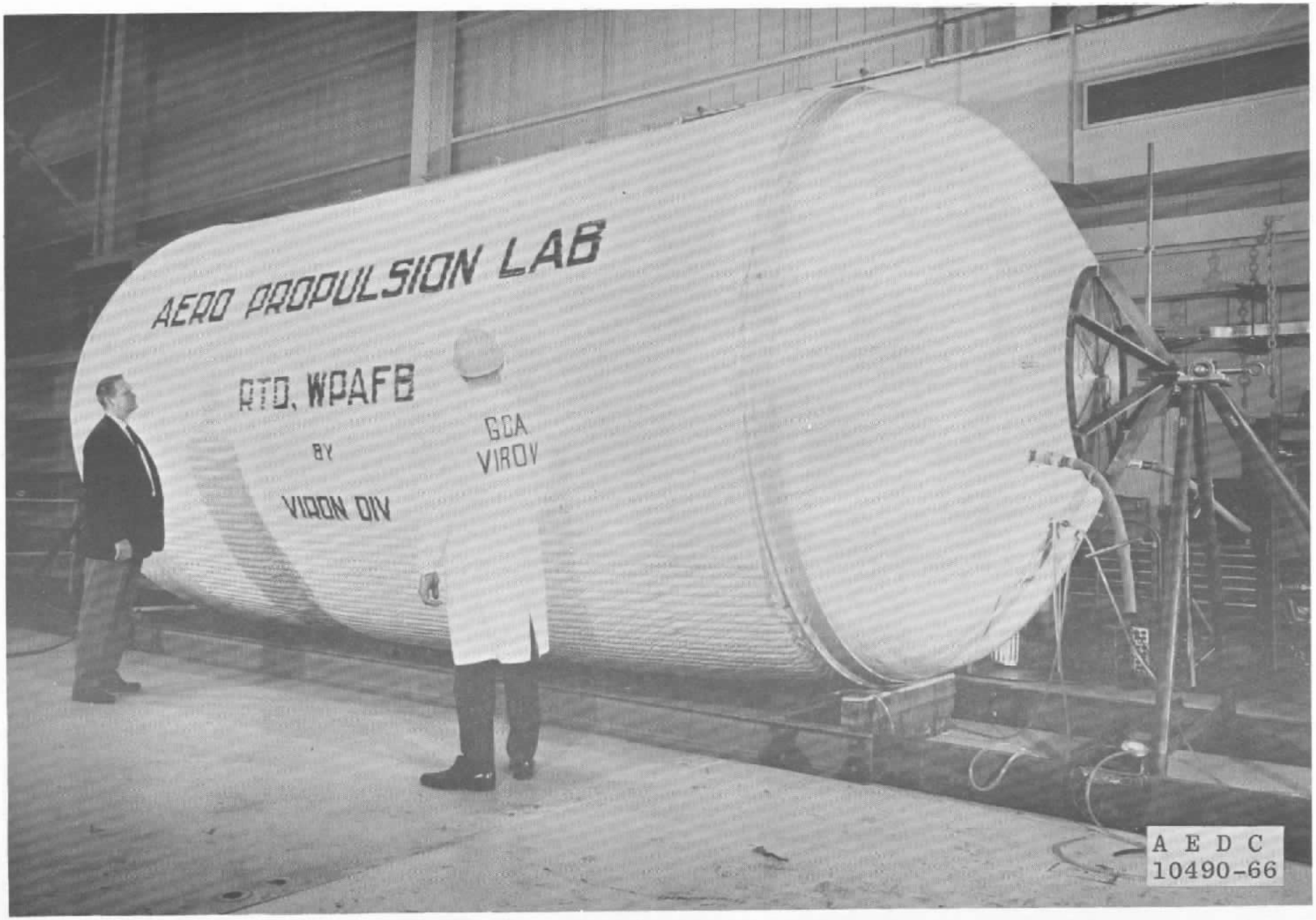

Fig. 11 Expanded and Pressurized Shelter in Handling Fixture

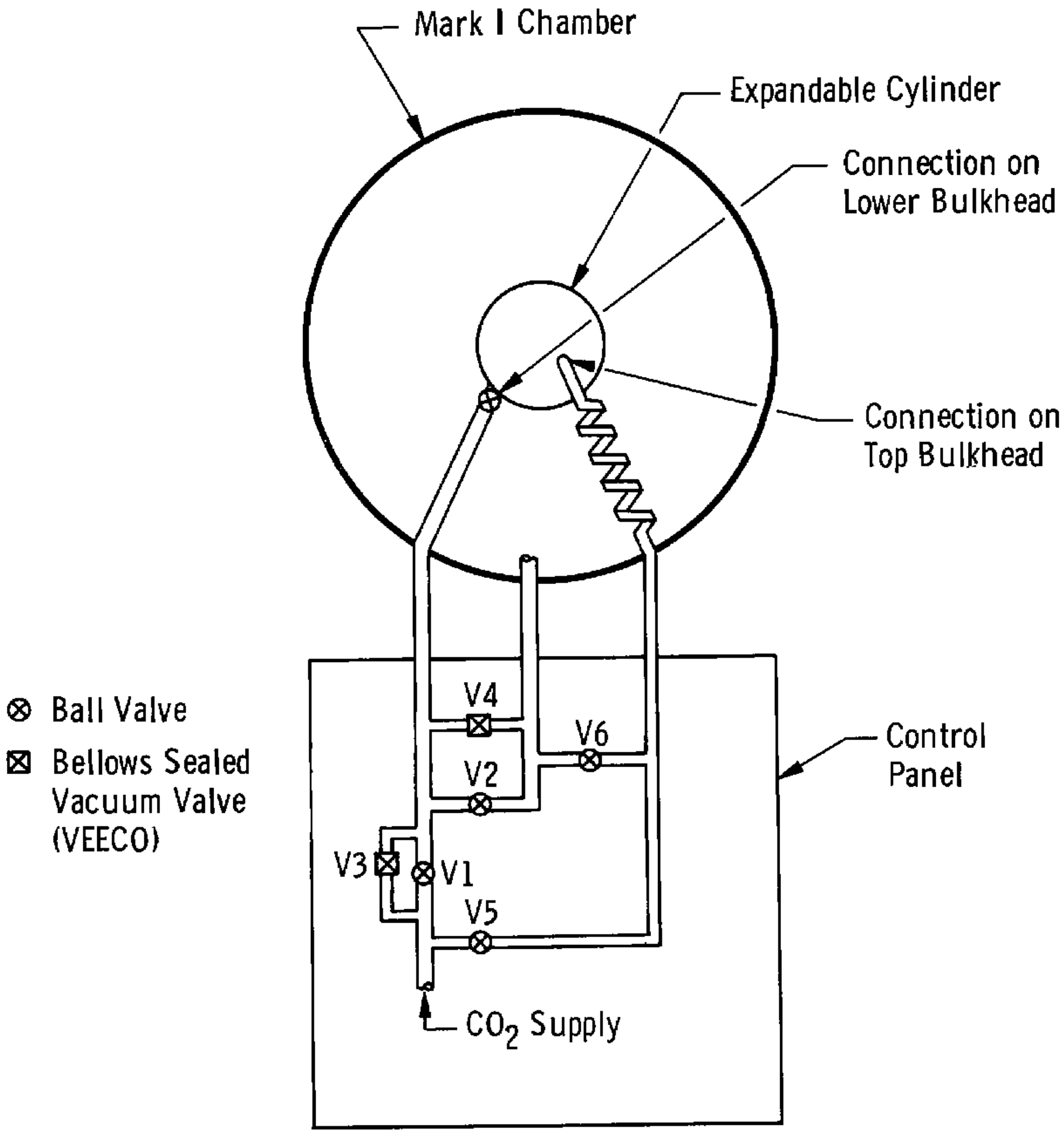

Fig. 12 Expandable Shelter Evacuation and Pressurization Schematic

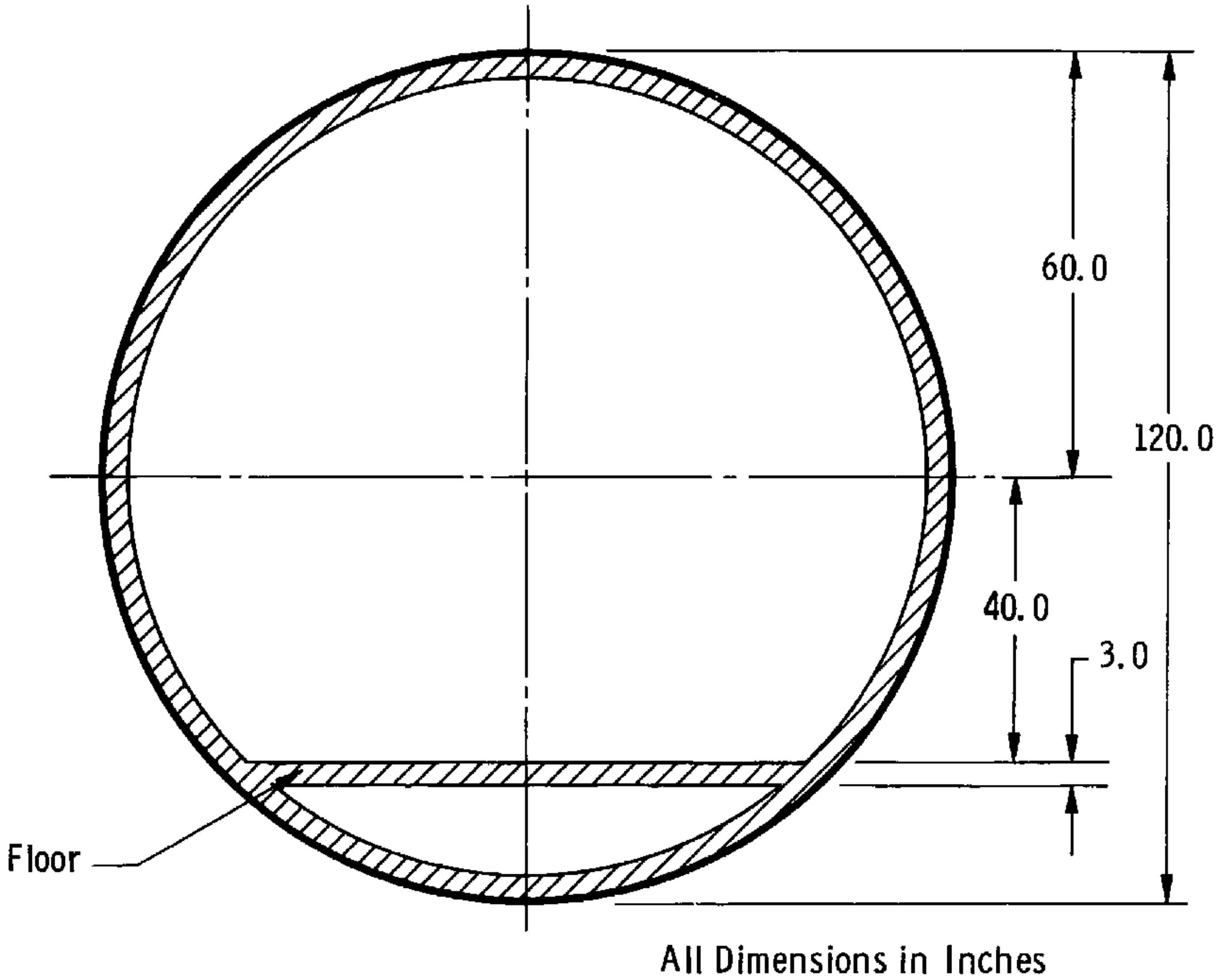

Fig. 13 Cross Section of Cylinder Showing Floor Position

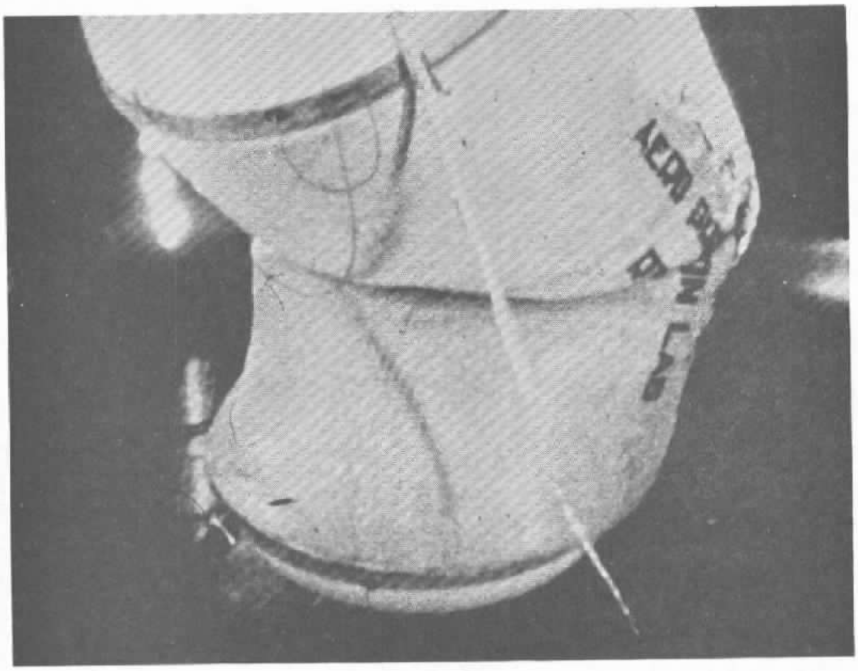

Fig. 14 Shelter Configuration 1.125 sec after Explosive Bolts Fired

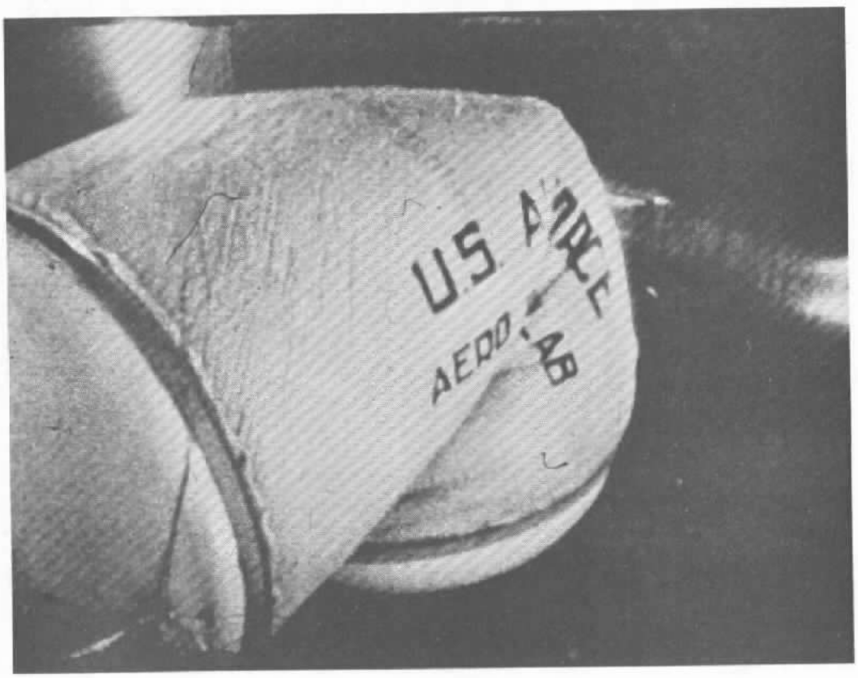

Fig. 15 Shelter Configuration 2.33 sec after Explosive Bolts Fired

Fig. 16 Expanded and Rigidized Shelter

Fig. 17 Inside of Lower Bulkhead after Shelter Rigidization

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13 ABSTRACT

A 10-ft-diam by 25-ft-long, expandable, self-rigidizing, cylindrical aerospace shelter was impregnated with a water setting resin and packaged for deployment in a vacuum of 10^{-4} torr in the Mark I Aerospace Environmental Chamber. Deployment of the structure occurred at an excessively high, uncontrolled rate. The test article and support equipment suffered extensive damage, which prevented continuation of the test in the vacuum. The Mark I chamber was returned to atmospheric conditions, and the structure was rigidized.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1 aerospace shelters						
2 expandable ~~cylinder type~~ bodies						
assembly						
resin impregnation						
deployment testing 19-4						
3. Space shelters						
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